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BEHAVIOR OF HYDRAZINE COMPOUNDS IN HARD AND SOFT WATER

AEROSPACE MEDICAL RESEARCH LABORATORY

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AEROSPACE MEDICAL DIVISION
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

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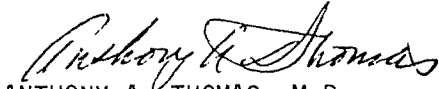
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FOR THE COMMANDER



ANTHONY A. THOMAS, M.D.
Director, Toxic Hazards Division
6570th Aerospace Medical Research Laboratory

Block 19 (continued)

pH
Specific Conductance
Water Hardness
Dissolved Oxygen (DO)

Coordination of Ions
Acute Toxicity
Static Bioassay

Block 20 (continued)

between hard and soft water, indicating an appreciable amount of coordination of hydrazine compounds with calcium and other hard water ions. The oxygen level was reduced by all four compounds at 100 mg/l usually within the first day; in one detailed study, hydrazine in hard water caused the greatest drop in DO at 5 to 13 hours of exposure. In general, the propellant effects were not of a magnitude to preclude conducting acute toxicity tests in an open static bioassay.

PREFACE

This study was initiated by the Toxic Hazards Division of the Aerospace Medical Research Laboratory. The research was performed in support of Project 6302, "Toxic Hazards of Propellants and Materials."

The author acknowledges the invaluable technical assistance of Sergeant Edwin E. Ray in this study and thanks Captain William T. Gormley and Mr. Plummer Sampson for conducting stability tests on the AutoAnalyzer, and Sergeant Ray and Miss Anita Gossett for conducting continuous dissolved oxygen measurements.

INTRODUCTION

Hydrazine compounds have been under investigation in this laboratory in a continuing program to evaluate the pollution potential of highly toxic substances used widely by the military and industry. The four hydrazine compounds examined were hydrazine, 1,1-dimethylhydrazine (known also as unsymmetrical dimethylhydrazine, UDMH), Aerozine-50 (an equal mixture of hydrazine and UDMH), and monomethylhydrazine (MMH). Like beryllium, which was studied earlier in the program, each of these compounds serves as a rocket fuel or propellant that ignites spontaneously upon contact with an oxidizer. The hydrazines, in themselves, are reducing or anti-oxidant agents and thus have many applications in industry (see, e.g., Audrieth and Ogg, 1951, chap 12); of these four compounds, hydrazine and MMH are especially strong reducing agents. All four compounds are weakly alkaline and very hygroscopic and, because of chemical similarities, exhibit certain physical characteristics similar to ammonia, which is also a common dissociation product of each. General information concerning the physical/chemical properties, hazards, proper handling, storage, equipment cleaning, transportation, and disposal exists for hydrazine, MMH and UDMH (JANNAF Propulsion Committee, 1970), and for Aerozine-50 (Bell Aerosystems Co., 1962). Detailed information on the chemistry of hydrazine only was published in 1951 by Audrieth and Ogg; results of an environmental pollution study of hydrazine, UDMH and Aerozine-50 that included factors affecting their decomposition in water were reported in 1964 by Hoover et al.; and a review of the biological effects, including

metabolism and toxicology, of hydrazine, methyl- and dimethylhydrazine was reported in 1968 by Clark et al.

The present effort was undertaken to determine the effects of all four hydrazine compounds on aqueous solutions prior to studying their effects on aquatic organisms. The aqueous environment consisted of hard and soft water, respectively. Each represents a different medium in which the biological effect or toxicity of a chemical pollutant may be different, as was discussed in a previous report (Slonim, 1971). This study deals primarily with determining the effects of these compounds on various parameters of hard and soft water, in particular to see if any hydrazine compound causes a significant change in the water (e.g., in pH or oxygen content) that would require modifications in a bioassay in order to study toxicant effects on aquatic species. The parameters include physical characteristics, alkalinity, pH, specific conductance, water hardness, and dissolved oxygen. This phase of work will serve as a basis for subsequent phases, the results of which will be reported elsewhere.

EXPERIMENTAL

A detailed description of the equipment, materials (glassware, reagents, etc.), source and preparation of test waters, and analytical procedures used in conjunction with this study was provided previously (Slonim, 1971; 1973). Aqueous samples were analyzed according to procedures described in Standard Methods (APHA et al., 1965). Hydrazine solutions were also subjected to specialized tests, such as by the AutoAnalyzer (Technicon Instruments) and continuous monitoring of oxygen content by means of a Varian two-pen attachment to the YSI Oxygen Analyzer.

The distilled water used for making soft water from hard water and for all analytical reagents and standard solutions was prepared by redistilling commercially-prepared distilled water through an all-glass distillation apparatus. This water had a pH of 6.3 to 6.4, a specific conductance of less than 2 $\mu\text{mho/cm}$, and no detectable Ca, Mg or Cu as determined by atomic absorption analysis.

The hard water was the supernate of raw ground water that was collected in large plastic carboys and allowed to stand for one week for sedimentation. Following this, the clear supernate was siphoned into a large (over 50-l capacity) polyethylene carboy (with spigot), where it was stored without further treatment ready for use. The hard water had a pH of 7.8 to 8.2, dissolved oxygen (DO) of 6.9 to 7.8 mg/l, hardness (EDTA) of 400 to 500 mg/l as CaCO_3 , specific conductance of 700 to 870 $\mu\text{mho/cm}$, and total alkalinity of 185 to 232 mg/l as CaCO_3 . It had no detectable amount of chlorine, copper or iron (Slonim, 1971).

This copper-free quality of water is especially desirable not only because copper is toxic to fish (like many other metals as well as chlorine), but it has been shown to cause appreciable degradation of hydrazine, UDMH and Az-50 in solution (Hoover et al., 1964).

Soft water was prepared just before use by making a 1:20 dilution of the hard water with glass distilled water and placing it in a 19-l carboy (with spigot). It had a pH of 6.3 to 6.9, hardness of 20 to 25 mg/l, DO of 6.9 to 7.8 mg/l, specific conductance of 50 to 65 $\mu\text{mho/cm}$, and alkalinity of 16 to 18 mg/l.

The hydrazine compounds used were liquids (bottled in 100 gram quantities) from Matheson Coleman & Bell and were of relatively high purity (minimum 97%). The hydrazine [$\text{H}_2\text{N}\cdot\text{NH}_2$] was in anhydrous form and over 97% pure, the remainder being primarily water. The unsymmetrical dimethylhydrazine (UDMH) [$(\text{CH}_3)_2\text{N}\cdot\text{NH}_2$] was also in anhydrous form and had a purity of at least 99%. Monomethylhydrazine (MMH) [$(\text{CH}_3)\text{HN}\cdot\text{NH}_2$] was at least 98% pure, the rest being mainly water. Aerozine-50 (Az-50) was prepared in this laboratory by making an equal weight mixture (50% each) of hydrazine and UDMH, so that 100 mg/l Az-50 consisted of 50 mg/l of each of its two components. This represents a slight difference to that used in aerospace systems, where a "50/50 fuel blend of hydrazine and UDMH" by weight percent is, according to specification MIL-P-27402 (USAF), $51 \pm 0.8\%$ hydrazine, 47% (min) UDMH + amines, and 1.8% water + other soluble impurities (USAF Mil. Spec., 1967).

Each of the four hydrazine compounds was carefully and accurately made into hard water (HW) and soft water (SW) solutions, respectively, starting with a stock standard (HW or SW) solution freshly prepared

before the start of each test. Varying small amounts of stock solution were pipetted into 2-liter volumetric flasks and diluted to volume to make a concentration of chemical ranging from 10^2 to 10^{-1} mg/l. Then each hard and soft water test solution was placed in a 1-gallon (3.8-l) widemouthed bioassay jar; two liters each of hard and soft water served as controls, respectively. The preparation of stock solutions of Aerozine-50 was slightly different than that of the other three because it is an equal weight mixture of two compounds. Since the density of anhydrous hydrazine is about 27% greater than that of UDMH, any stock standard solution of Az-50 is made by combining hydrazine and UDMH liquids in a volumetric ratio of 1.00 ml hydrazine to 1.25 ml UDMH and diluting to volume with water in a volumetric flask.

Various physical properties, phenolphthalein and total alkalinity, pH, specific conductance, water hardness, and dissolved oxygen were examined immediately following preparation of fresh solutions and at the same time each day for 4 days (an acute toxicity period). More frequent measurements were made to assess the effects of a propellant on the oxygen content of water and to some extent chemical stability in the test solution. Hydrazine stability or degradation in various types of water is presently under investigation using a recently developed polarographic method, and the results will be reported at a later date.

Hydrazine, UDMH and Aerozine-50 were always analyzed at the same time. At a later period, MMH was investigated, so that the hard and soft water control values were not identical to those for the other three hydrazines. The data for all four hydrazine compounds are tabulated under each parameter, respectively.

RESULTS AND DISCUSSION

Physical Properties

Each of the three basic hydrazines as well as the Aerozine-50 mixture was a clear, colorless liquid and very soluble in water. Only MMH in hard water at a concentration at or above 1,000 mg/l showed some degree of turbidity. Each compound exhibited an ammonia-like odor, with a somewhat more fishy odor present in UDMH. However, the ammoniacal odor of each one was not too apparent at concentrations up to 100 mg/l used in this study. In view of the endothermic nature of these compounds, there was no noticeable change in temperature (i.e., greater than 0.5C) of any of the chemical solutions in the concentration range used.

The results of preliminary studies conducted on the AutoAnalyzer by others in the laboratory to determine the stability of hydrazine compounds in hard and soft water were that hydrazine, itself, was fairly stable. In one test, hydrazine originally made up at 100 mg/l was found to be at 72 hours 90 mg/l in soft water and 87 mg/l in hard water. In another analysis, 25 and 50 mg/l hydrazine solutions were found to be at 96 hours 27.6 and 55.0 mg/l in soft water and 24.1 and 47.0 mg/l in hard water, respectively. In single pilot tests only with this instrument, UDMH was shown to be present at 48 hours and Aerozine-50 at 72 hours. The stability of all three compounds appeared to be slightly greater in soft water than hard water. Subsequent work with a recently developed polarographic technique specific for hydrazine confirmed that hydrazine was very stable in soft water but less so in hard water over a 96-hour period.*

* Slonim, A.R., and Gisclard, G.B.: Manuscript in preparation.

Alkalinity

Alkalinity in general is a measure of the proton acceptor capacity of the water and is expressed in terms of the bicarbonate, carbonate, and hydroxide fractions that are stoichiometrically related to each other (determined by ratio of phenolphthalein to total alkalinities). This classification of total alkalinity into three major forms assumes that the amount of other weak acid radicals present is negligible and that bicarbonate and hydroxide alkalinities are incompatible in the same water sample. Of these three forms, hydroxide alkalinity was not involved in the test waters used here, since the phenolphthalein alkalinity was always less than half of total alkalinity. The carbonate and bicarbonate alkalinities, on the other hand, are compatible with the high carbonate/bicarbonate content of the raw water used for making up the test waters. What effect hydrazine compounds which are strong reducing agents have on the proton acceptor capacity (the alkalinity) of hard and soft water was examined, and the results are shown in Table 1*:

Hydrazine at low concentrations (0.1 and 1 mg/l) did not change alkalinity in either hard or soft water. However, at 100 mg/l there was a significant increase in both phenolphthalein and total alkalinities much greater in soft water (about 7-fold) than in hard water (about 1.3-fold) over the control values. UDMH, on the other hand, had little or no effect on phenolphthalein alkalinity even at 100 mg/l, but caused an increase in total alkalinity in hard water and a very significant increase in soft water to the same degree as hydrazine. Aerozine-50 produced a slight increase in phenolphthalein alkalinity at the 100 mg/l level somewhat halfway between hydrazine and UDMH (cf., e.g., all three

*Figures and tables are located at end of report.

compounds at 48-hr) and, similar to its two components, caused a very significant increase (9-fold) in total alkalinity in soft water and a small but consistent increase (1.3-fold) in hard water. MMH, like UDMH, did not affect phenolphthalein alkalinity, but at 100 mg/l caused a very significant increase (7-fold) in total alkalinity in soft water and little or no increase in hard water. Thus, all four hydrazine compounds affected the alkalinity of soft water at the 100 mg/l level much more than that of hard water, in which their binding with calcium and other ions occurs. Hydrazine appeared to have the most effect on both types of alkalinities due perhaps to its capacity to donate protons more readily than its methylated derivatives. The changes observed in the alkalinities with time were not significant nor consistent.

pH

The effects on pH of the hydrazine compounds in hard and soft water are shown in Table 2. Hydrazine in low concentrations in either hard or soft water did not alter the pH. At a concentration of 100 mg/l, there was an increase in pH initially from 7.6 to 8.4 in hard water and a greater increase in soft water, from 6.9 to 8.6; in each case, the difference from control values became less with time. UDMH produced the same results as hydrazine, except that all the solutions at 100 mg/l were slightly less alkaline than the 100 mg/l hydrazine solutions. Likewise, Aerozine-50 gave the same pH response with increasing concentration and over time as the other two compounds, but showing pH values closer to hydrazine than UDMH at the 100 mg/l level. MMH produced an appreciable increase in pH also in both hard and soft water only at the 100 mg/l concentration; the values of all MMH solutions with time were inconsistent.

Although the pH of soft water was always lower than hard water, all the hydrazine compounds at 100 mg/l caused a larger increase in pH in soft water than hard water, due in some degree to the buffering action of hard water against the hydrazines. None of the solutions became very alkaline at 100 mg/l and thus would present no problem in toxicity studies with the kinds of fish used previously (Slonim, 1973).

Conductivity

The results concerning the effects of the hydrazine compounds on the specific conductance of hard and soft water solutions are shown in Table 3. A specific conductance of 1000 $\mu\text{mho/cm}$ on the conductivity bridge used (Slonim, 1971) is equivalent to that of a 7.9 mM (590 mg/l) KCl standard solution. The only significant change produced by hydrazine, which is a good electrolyte solvent and coordinates well with cations due to its high dielectric constant, was an increase in specific conductance that was at least doubled from 24 to 96 hours at the 100 mg/l level in soft water; the slightly lower than control conductivity value in hard water at 100 mg/l indicates some degree of binding of hydrazine with calcium and other hard water ions. UDMH only at a concentration of 100 mg/l caused also an increase in conductivity in soft water and showed slightly lower than control values in hard water starting at 24 hours. Aerozine-50 had the same effect as the others, but resembled hydrazine more than UDMH at 100 mg/l in soft water, respectively. MMH at 100 mg/l also produced a significant increase in the specific conductance in soft water but a slight reduction from the control value in hard water. Thus, hydrazine, Aerozine-50 and MMH all showed a significant change from control values between soft and hard water solutions at 100 mg/l, with

the greater change occurring in soft water (where there is less binding). UDMH, on the other hand, appeared to be the least affected by the difference in the amount of electrolytes present between hard and soft water.

Hardness

The effects of the hydrazine compounds on water hardness are shown in Table 4. All four compounds tested did not increase EDTA hardness with increasing concentration, but in time showed a small decrease at the 100 mg/l level in hard water, the difference from the control value being the largest with hydrazine and the smallest with UDMH. There was no consistent change with any of the compounds in soft water. The reduction in hardness observed at 100 mg/l of each chemical in hard water suggests that coordination or binding of calcium ions with hydrazine compounds becomes appreciable at that concentration level and that the degree of binding is less in the case of UDMH than the other propellants. This latter observation in combination with others described above suggest further that UDMH may affect aquatic organisms differently than the other three compounds.

Oxygen

The results concerning the effects of hydrazine compounds on dissolved oxygen (DO) in hard and soft water are shown in Table 5. Hydrazine at low concentrations did not change the oxygen content of hard or soft water. At 100 mg/l the DO level was reduced instantaneously and remained lower than the controls throughout the test period. The lowest level was 5.98 mg/l in hard water at 24 hours, and in soft water it was 6.18 mg/l at 48 hours; both levels were safe, that is, above 4 mg/l for warm-water organisms (APHA et al., 1965, p 551). UDMH at low concentrations behaved

the same as hydrazine; 100 mg/l in soft water also did not alter the DO level. UDMH at 100 mg/l in hard water, on the other hand, caused a drop in DO at the beginning that was lowered to 4.68 mg/l at 24 hours, but gradually climbed near the control value after 48 hours. Aerozine-50 at low concentrations behaved like its two components and at 100 mg/l lowered the DO from approximately 8 to 7 mg/l in both types of water at the start. The greatest effect occurred in 24 hours where the DO dropped to 3.9 mg/l in hard water (but only to 6.85 mg/l in soft water); it reached a safe level (4.68 mg/l) at 48 hours and continued to climb but remained significantly lower than control values throughout the test period. MMH at low concentrations, like the other three hydrazines, did not alter the DO level in either type of water. At the start 100 mg/l MMH caused only a slight reduction in the DO level. However, in contrast to the other compounds, MMH at 100 mg/l caused the greatest drop in DO to occur in soft water (to 5.0 mg/l as compared to 6.2 mg/l in hard water) at 24 hours. The DO remained lower in soft water than in hard water and also was significantly lower in hard and soft MMH solutions than the controls throughout the test period.

Early in the program, there was concern that analysis of DO once per day at the same time of day might easily miss the point of the greatest effect of hydrazine on the oxygen content of water. Since the data indicated a greater effect in hard water than soft water at 100 mg/l hydrazine (see Table 5), an experiment was conducted, after several trial runs, to monitor the effect of 10 mg/l hydrazine on oxygen in hard water every hour for a period up to 72 hours. Both the hard water control and hydrazine solution were stirred at the same uniform rate, each by means

of a teflon-coated magnetic stirring rod in solution and magnetic stirrer. The oxygen content was monitored by a Clark-type, membrane-covered polarographic probe kept in each solution and connected to a YSI oxygen meter, the signal from which was fed via a two-pen attachment to a Varian recorder. The results are illustrated in Figure 1. The low DO levels plotted on the graph were due to the slow rate of stirring, which was set to approximate as much as possible the static conditions of all the tests as well as the type of bioassay to be undertaken subsequently. The results showed that the difference in DO level between hydrazine and the hard water control was usually never greater than 0.5 to 1.0 mg/l; this was true also at the higher stirring rates. The time when the oxygen dropped to its lowest level was at 5 hours and was still low for a period of 8 hours, after which the DO level of the hydrazine solution returned to a relatively steady level (fluctuating only ± 0.2 mg/l) and was always below 1.0 mg/l less than the control DO level for the remainder of the test period.

SUMMARY AND CONCLUSIONS

The four hydrazine compounds in the concentration range tested exhibited similar physical characteristics in aqueous solutions and appeared to be more stable to some degree, especially hydrazine, in soft water than hard water; the degradation of these compounds in hard water (hence lower stability) is probably enhanced by the various ions present. Low concentrations such as 0.1 and 1.0 mg/l of each of the four hydrazine compounds had no significant effect on any of the parameters evaluated. All four compounds at the 100 mg/l concentration level produced a relatively greater effect on total alkalinity, pH and specific conductance in soft water than hard water, along with a small drop in EDTA hardness over time in hard water only, indicating that the hydrazine compounds coordinate with calcium and other ions present in hard water; the degree to which binding occurs differs among these compounds, being the highest for hydrazine and lowest for UDMH where only two of four sites on the nitrogen atoms are readily available for coordination. The greatest change in oxygen content was produced in hard water by hydrazine, UDMH and Aerozine-50, but in soft water by MMH. The largest drop in DO by hydrazine was observed to occur at 5 hours and remain at a low level for 8 hours. The decrease in the oxygen content of the water by all the compounds at 100 mg/l usually occurred within the first 24 hours; however, the lowest oxygen levels seen recovered in time in this open test system. In general, none of the parameters evaluated were altered to the extent that toxicity studies could not be undertaken in an open static biological assay

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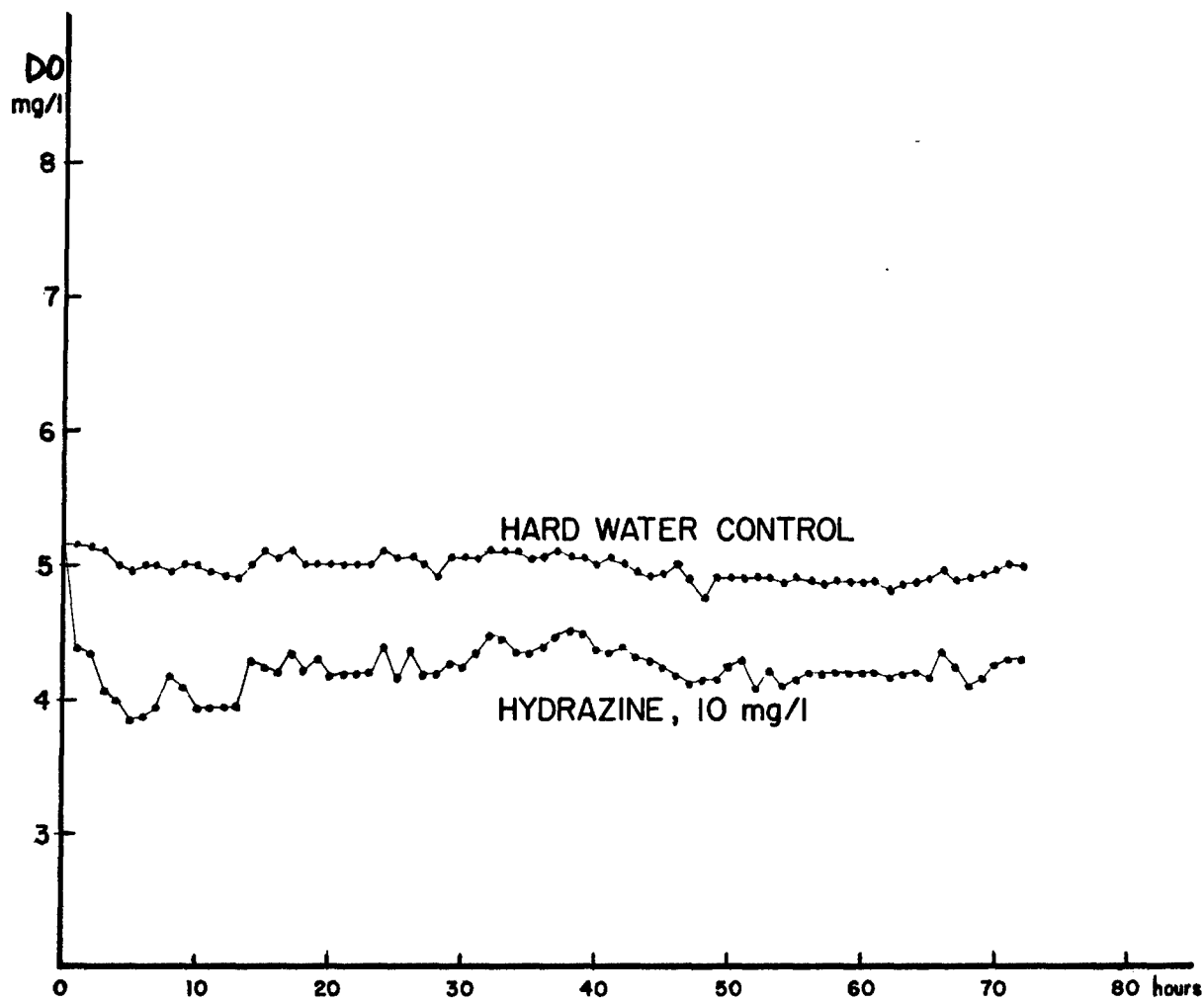


Figure 1. Continuous monitoring of effect of 10 mg/l hydrazine on dissolved oxygen in hard water. Each point represents hourly value (hard water: 464 mg/l as CaCO_3).

TABLE 1. EFFECT OF THE HYDRAZINES ON ALKALINITY

Compound	Water	Conc. (mg/l)	Alkalinity, mg/l (as CaCO ₃)					
			Phenolphthalein			Total		
			0	48	96 hr	0	48	96 hr
Hydrazine	Hard	0	18	16	12	232	232	212
		0.1	6	14	10	226	220	184
		1	--	14	16	--	234	224
		100	50	38	26	340	290	250
	Soft	0	0	0	0	16	16	16
		0.1	0	0	0	12	16	14
		1	0	0	0	16	18	18
		100	54	36	20	130	128	96
UDMH	Hard	0	18	16	12	232	232	212
		0.1	12	16	14	234	224	208
		1	10	14	14	232	224	204
		100	20	14	14	314	262	262
	Soft	0	0	0	0	16	16	16
		0.1	0	0	0	14	16	24
		1	0	0	0	14	16	18
		100	12	8	10	114	106	134
Az-50	Hard	0	18	16	12	232	232	212
		0.1	12	12	14	230	214	198
		1	--	14	14	232	216	200
		100	16	26	24	342	292	272
	Soft	0	0	0	0	16	16	16
		0.1	0	0	0	14	16	16
		1	2	0	0	18	18	18
		100	28	12	14	146	146	148
MMH	Hard	0	0	0	2	228	248	214
		0.1	0	0	0	208	236	228
		1	0	0	0	234	234	200
		100	0	0	0	316	260	210
	Soft	0	0	0	0	--	15	14
		0.1	0	0	0	8	12	12
		1	0	0	0	10	14	12
		100	8	6	0	102	102	100

TABLE 2. EFFECT OF THE HYDRAZINES ON pH

Compound	Water	Conc. (mg/l)	pH				
			0	24	48	72	96 hr
Hydrazine	Hard	0	7.60	8.00	8.15	8.16	8.15
		0.1	7.68	8.08	8.11	7.98	8.00
		1	7.70	8.10	8.20	8.23	8.25
		100	8.35	8.30	8.23	8.18	8.20
	Soft	0	6.90	6.80	7.12	7.24	7.30
		0.1	6.94	6.94	7.39	7.32	7.25
		1	7.25	7.10	7.28	7.31	7.25
		100	8.60	8.12	8.08	8.02	7.90
UDMH	Hard	0	7.60	8.00	8.15	8.16	8.15
		0.1	7.65	8.10	8.18	8.21	8.10
		1	7.75	8.10	8.19	8.13	8.10
		100	8.00	8.15	8.10	8.08	8.05
	Soft	0	6.90	6.80	7.12	7.24	7.30
		0.1	7.15	7.35	7.48	7.27	7.25
		1	7.20	7.20	7.34	7.24	7.24
		100	8.40	8.00	7.94	7.79	7.65
Az-50	Hard	0	7.60	8.00	8.15	8.16	8.15
		0.1	7.75	8.10	8.12	8.11	8.00
		1	7.75	8.10	8.19	8.15	8.00
		100	8.25	8.25	8.18	8.13	8.00
	Soft	0	6.90	6.80	7.12	7.24	7.30
		0.1	7.30	7.25	7.49	7.24	7.20
		1	7.35	7.28	7.37	7.24	7.25
		100	8.60	8.20	8.12	7.96	7.82
MMH	Hard	0	--	7.75	8.10	8.25	8.35
		0.1	7.62	8.10	7.55	8.15	8.10
		1	7.71	8.10	8.01	8.03	8.15
		100	8.26	8.25	8.05	8.15	8.25
	Soft	0	--	7.15	7.80	7.75	7.89
		0.1	7.31	7.24	6.95	7.50	7.75
		1	7.73	7.24	7.57	7.59	8.05
		100	8.93	8.65	8.45	8.05	8.18

TABLE 3. EFFECT OF THE HYDRAZINES ON SPECIFIC CONDUCTANCE

Compound	Water	Conc. (mg/l)	Specific Conductance, $\mu\text{mho/cm}$				
			0	24	48	72	96 hr
Hydrazine	Hard	0	750	780	739	758	750
		0.1	770	770	723	729	730
		1	720	723	733	753	762
		100	745	719	682	678	700
	Soft	0	50.0	53.5	50.0	53.5	56.0
		0.1	57.0	52.5	50.0	54.2	56.0
		1	56.0	53.5	52.1	57.5	58.5
		100	78.0	98.3	105.7	119.3	132.0
UDMH	Hard	0	750	780	739	758	750
		0.1	750	753	734	753	750
		1	760	748	720	748	762
		100	780	762	704	722	735
	Soft	0	50.0	53.5	50.0	53.5	56.0
		0.1	63.0	52.0	48.8	53.3	56.0
		1	56.0	52.9	52.2	56.9	59.0
		100	65.0	64.8	65.0	78.2	80.0
Az-50	Hard	0	750	780	739	758	750
		0.1	770	770	719	732	750
		1	770	765	719	729	750
		100	770	753	692	720	710
	Soft	0	50.0	53.5	50.0	53.5	56.0
		0.1	56.0	52.8	50.1	55.9	57.0
		1	53.0	53.3	50.3	57.9	57.0
		100	67.0	84.5	89.7	112.2	112.2
MMH	Hard	0	--	800	790	749	749
		0.1	670	770	740	710	705
		1	790	780	750	740	710
		100	749	730	720	690	690
	Soft	0	--	48	50	46	52
		0.1	55	46	48	48	43
		1	47	40	40	40	41
		100	67	77	79	90	90

TABLE 4. EFFECT OF THE HYDRAZINES ON WATER HARDNESS

Compound	Water	Conc. (mg/l)	EDTA Hardness, mg/l (as CaCO ₃)		
			0	48	96 hr
Hydrazine	Hard	0	416	416	372
		0.1	408	408	380
		1	416	420	372
		100	404	348	310
	Soft	0	20	24	28
		0.1	34	24	24
		1	34	--	24
		100	28	28	52
UDMH	Hard	0	416	416	372
		0.1	408	420	392
		1	408	416	392
		100	408	392	360
	Soft	0	20	24	28
		0.1	24	28	24
		1	20	24	24
		100	24	28	32
Az-50	Hard	0	416	416	372
		0.1	408	412	384
		1	408	412	436
		100	404	376	332
	Soft	0	20	24	28
		0.1	32	28	24
		1	20	28	24
		100	24	24	28
MMH	Hard	0	--	364	372
		0.1	--	368	392
		1	--	364	372
		100	--	320	332
	Soft	0	--	16	20
		0.1	--	16	18
		1	--	16	20
		100	--	22	20

TABLE 5. EFFECT OF THE HYDRAZINES ON DISSOLVED OXYGEN

Compound	Water	Conc. (mg/l)	DO, mg/l				
			0	24	48	72	96 hr
Hydrazine	Hard	0	7.90	8.25	7.85	7.70	7.54
		0.1	7.92	8.15	7.85	7.80	7.52
		1	7.77	--	7.65	7.80	7.45
		100	7.02	5.98	5.95	6.12	5.90
	Soft	0	7.98	8.40	7.82	7.80	7.55
		0.1	7.88	8.39	7.78	7.75	7.58
		1	7.85	8.20	7.81	7.85	7.60
		100	7.00	7.08	6.18	7.25	7.02
UDMH	Hard	0	7.90	8.25	7.85	7.70	7.54
		0.1	7.91	8.18	7.82	7.70	7.39
		1	8.02	8.20	7.73	7.70	7.30
		100	7.36	4.68	6.20	7.20	7.32
	Soft	0	7.98	8.40	7.82	7.80	7.55
		0.1	7.83	8.18	7.89	7.80	7.43
		1	7.68	8.10	7.88	7.75	7.33
		100	7.90	8.12	7.85	7.80	7.32
Az-50	Hard	0	7.90	8.25	7.85	7.70	7.54
		0.1	7.80	8.20	7.92	7.75	7.54
		1	7.85	8.08	7.78	7.80	7.59
		100	6.95	3.90	4.61	5.95	6.68
	Soft	0	7.98	8.40	7.82	7.80	7.55
		0.1	7.87	8.18	7.95	7.90	7.58
		1	7.83	8.20	7.97	7.85	7.50
		100	7.17	6.85	7.40	7.60	7.38
MMH	Hard	0	7.90	7.60	7.70	8.15	8.15
		0.1	8.01	7.80	7.80	8.15	8.15
		1	7.97	7.70	7.70	8.10	8.05
		100	7.73	6.20	6.40	6.80	6.90
	Soft	0	7.90	7.50	7.70	8.15	8.18
		0.1	7.90	7.75	7.75	8.15	8.18
		1	7.97	7.80	7.70	8.15	8.15
		100	7.50	5.00	5.50	6.30	6.30